The AEROVOX Research Worker

The Aerovox Research Worker is a monthly house organ of the Aerovox Corporation. It is published to bring to the Radio Experimenter and Engineer authoritative, first hand information on condensers and resistances for radio work.

VOL. 17, NO. 10 OCTOBER, 1945 50c per year in U. S. A. 60c per year in Canada

Design Data for Dividing Networks

By the Engineering Department, Aerovox Corporation

MODERN high-fidelity audio systems make use of separate high-frequency and low-frequency loudspeakers. In order to obtain maximum efficiency from this dual reproducing arrangement, *dividing networks* are connected between the amplifier output transformer and the voice coils of the tweeter (high-frequency speaker) and woofer (low-frequency speaker). These networks separate the frequency components in the amplifier output voltage into two bands, so that only frequencies above a certain *cross-over* frequency are transmitted to the tweeter, and only those below this cross-frequency are transmitted to the woofer. Each speaker thus operates only at those frequencies at which it is most efficient and faithful.

The cross-over frequency is selectable at will, but most commercially available dividing networks operate at cross-over frequencies of 400 or 800 cycles.

The basic facts concerning practical dividing networks may be summed up in the following brief comments:

(1) Each such network comprises a low-pass and high-pass filter with their input circuits connected either in series or in parallel. The output circuit of the high-pass filter section feeds the tweeter; that of the low-pass filter, the woofer.

(2) At the cross-over frequency, the high- and low-frequency power outputs are equal.

(3) With respect to the attenuation at the cross-over frequency, the dividing network provides 12 db minimum attenuation one octave from the cross-over frequency.

(4) The *constant-resistance* type of dividing network is a specific form which, when terminated in the proper resistance load, will offer a constant input resistance over a frequency band. The constant-resistance type network is convenient in some instances, since each of its capacitor components are identical in value, as are also each of its inductor components.

Circuit diagrams of dividing networks are given in Figures 2 and 3, together with the formulae for obtaining the values of their capacitor and inductor elements. The arrangements shown in Figure 2 are the conventional series- and parallel-connected filter-type networks. Those given in Figure 3 are constant-resistance networks. In the latter groups, two of the circuits (3-A and 3-B) will provide only about 6 db attenuation at 1 octave from the cross-over frequency, and should be employed only in those specific cases where this low attenuation may be tolerated.

POSITION OF NETWORK IN AMPLIFIER

The band-separating action of the dividing network might be obtained at several points in a conventional audio amplifier. In standard practice however, the dividing network is connected almost always between the secondary winding of the amplifier output transformer and the loudspeaker voice coils, as shown in Figure 1. In this way, one output amplifier stage is made to serve both loudspeakers.

Each network section must carry the full power delivered to the loudspeaker which it supplies. Network components accordingly must be capable of handling safely these power levels. At the same time, the resistance of the inductors must be of the lowest possible value, consistent with required inductance, in order to minimize insertion losses.

The impedances out of, and into which the practical dividing network operates are identical with the rated voice coil impedance of the speakers. This is the R_O value that appears in the formulae.

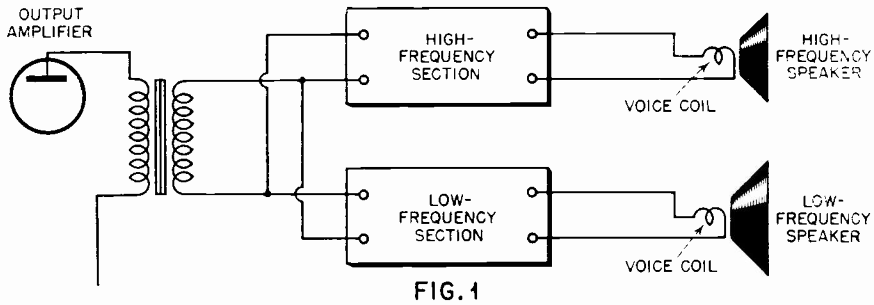


FIG. 1

USE OF THE TABLES

All component values for dividing networks may be calculated by means of the formulae given in Figures 2 and 3. However, we are printing here two tables which list these values calculated with sufficient accuracy for critical applications.

Tables I and II list all capacitor and inductor values required respectively in conventional and constant-resistance type dividing networks. These tables are based upon an R_O value of 10 ohms and a *m* of 0.6. All capacitance values are given in microfarads and all inductance values in millihenries, for common cross-over frequencies every 50 cycles apart from 100 to 1000 cycles.

When working with systems in which $R_O = 10$, all C and L values may be read in the corresponding frequency column directly from Chart I for conventional networks, or from Chart II for the constant-resistance type. For R_O values other than 10, the chart values may be operated upon to yield values required for the new impedance, thus: for a value (R_X) other than R_O (10 ohms), multiply all L values corresponding to the desired cross-over frequency by R_X/R_O, and divide all C values by this same factor.

As an illustration of the use of the R_X/R_O factor, consider the following example: A conventional dividing network is required to work between 16 ohms at a cross-over frequency of 450 cycles. At 16 ohms, $R_X/R_O = 16/10 = 1.6$. All L values in the 450-cycle column of Chart I must be multiplied by 1.6, and all C values in the same column must be divided by 1.6:

$$C_1 = 70.76/1.6 = 44.22 \text{ mfd.}$$
$$C_2 = 22.11/1.6 = 13.19 \text{ mfd.}$$
$$C_3 = 35.38/1.6 = 22.11 \text{ mfd.}$$
$$C_4 = 17.69/1.6 = 11.05 \text{ mfd.}$$
$$C_5 = 56.61/1.6 = 35.38 \text{ mfd}$$
$$L_1 = (5.66)\ 1.6 = 9.056 \text{ mh.}$$
$$L_2 = (3.54)\ 1.6 = 5.664 \text{ mh.}$$
$$L_3 = (1.77)\ 1.6 = 2.832 \text{ mh.}$$
$$L_4 = (7.08)\ 1.6 = 11.328 \text{ mh.}$$
$$L_5 = (2.21)\ 1.6 = 3.536 \text{ mh.}$$

To find the capacitance and inductance values required at 10 ohms for some cross-over frequency (f) in cycles per second, other than one of the 19 frequencies given in the two charts, first locate the C and L values in the 100-cycle column, then multiply each of these values by 100 f. If a different impedance (R_X) as well as a different frequency (f) is required, locate both the capacitance and inductance values in the 100-cycle column of the chart, and multiply the capacitances thus obtained by $1000/(fR_X)$, and the inductances by $(10R_X)/f$.

As an illustration of the use of these last two formulae, consider the following example: A constant-resistance dividing network is required with a cross-over frequency of 500 cycles, to work between 16 ohms. The 100-cycle values (Chart II) will be multiplied thus:

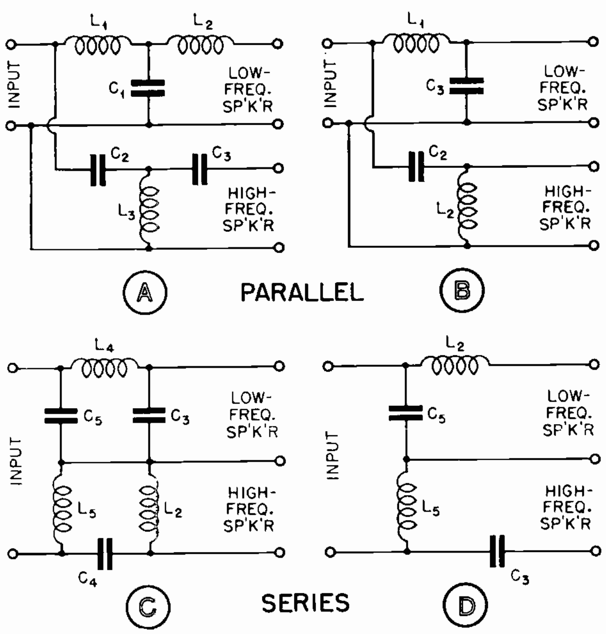
$$C_1 = 159.15 \times 0.125 = 19.89 \text{ mfd.}$$
$$C_2 = 225.04 \times 0.125 = 28.13 \text{ mfd.}$$
$$C_3 = 112.52 \times 0.125 = 14.06 \text{ mfd.}$$
$$L_1 = 15.91 \times 0.32 = 5.09 \text{ mh.}$$
$$L_2 = 11.25 \times 0.32 = 3.60 \text{ mh.}$$
$$L_3 = 22.50 \times 0.32 = 7.20 \text{ mh.}$$

$$\boxed{\begin{array}{c} 1000/(fR_X) = 1000/(500 \times 16) = 0.125 \\ (10R_X)/f = (10 \times 16)/500 = 0.32 \end{array}}$$

CHART II. Constant-Resistance Dividing Networks (See Fig. 3)

f_c=	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
C_1	159.15	106.15	79.62	63.69	53.08	45.49	39.81	35.38	31.85	28.95	26.54	24.49	22.74	21.23	19.90	18.75	17.69	16.76	15.91
C_2	225.04	150.10	112.58	90.06	75.05	64.32	56.29	50.03	45.03	40.93	37.53	34.63	32.15	30.02	28.14	26.51	25.01	23.69	22.50
C_3	112.52	75.05	56.29	45.03	37.52	32.16	28.14	25.01	22.51	20.46	18.76	17.31	16.07	15.01	14.07	13.25	12.50	11.84	11.25
L_1	15.91	10.61	7.96	6.37	5.31	4.55	3.98	3.54	3.18	2.89	2.65	2.45	2.27	2.12	1.99	1.87	1.77	1.68	1.59
L_2	11.25	7.50	5.63	4.50	3.75	3.22	2.81	2.50	2.25	2.04	1.87	1.73	1.60	1.50	1.41	1.32	1.25	1.19	1.12
L_3	22.50	15.00	11.26	9.00	7.50	6.44	5.62	5.00	4.50	4.08	3.74	3.46	3.20	3.00	2.82	2.64	2.50	2.38	2.24

C mfds. L mh R_O 10 f cycles



$C_1 = \frac{2}{\omega_c R_o}$ farad

$C_2 = \left(\frac{1}{1+m}\right)\frac{1}{\omega_c R_o}$ farad

$C_3 = \frac{1}{\omega_c R_c}$ farad

$C_4 = \frac{1}{2\,\omega_c R_o}$ farad

$C_5 = (1+m)\frac{1}{\omega_c R_o}$ farad

$L_1 = (1+m)\frac{R_o}{\omega_c}$ henry

$L_2 = \frac{R_o}{\omega_c}$ henry

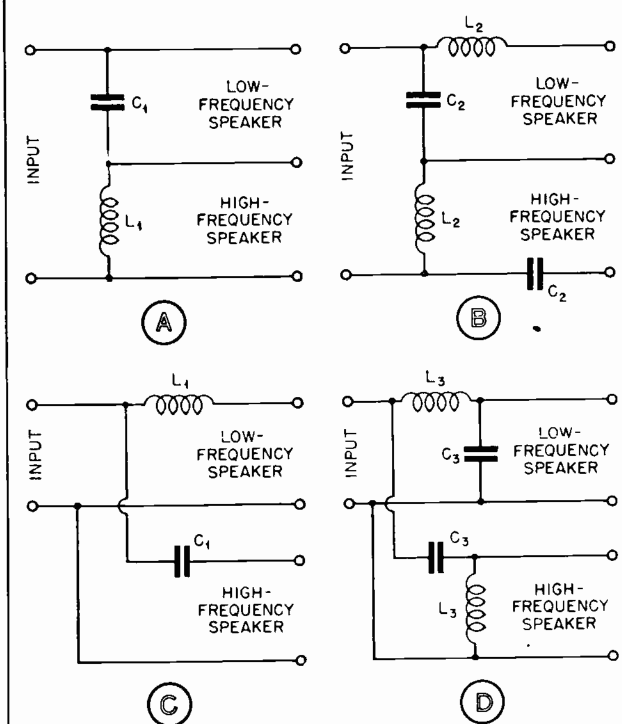
$L_3 = \frac{R_o}{2\,\omega_c}$ henry

$L_4 = \frac{2\,R_o}{\omega_c}$ henry

$L_5 = \left(\frac{1}{1+m}\right)\frac{R_o}{\omega_c}$ henry

f_c = Crossover frequency $m = 0.6$

CONVENTIONAL NETWORKS
FIG. 2



$C_1 = \frac{1}{\omega_c R_o}$ farad

$C_2 = \sqrt{2}\; C_1$ farad

$C_3 = \frac{C_1}{\sqrt{2}}$ farad

$L_1 = \frac{R_o}{\omega_c}$ henry

$L_2 = \frac{L_1}{\sqrt{2}}$ henry

$L_3 = \sqrt{2}\; L_1$ henry

f_c = Crossover frequency

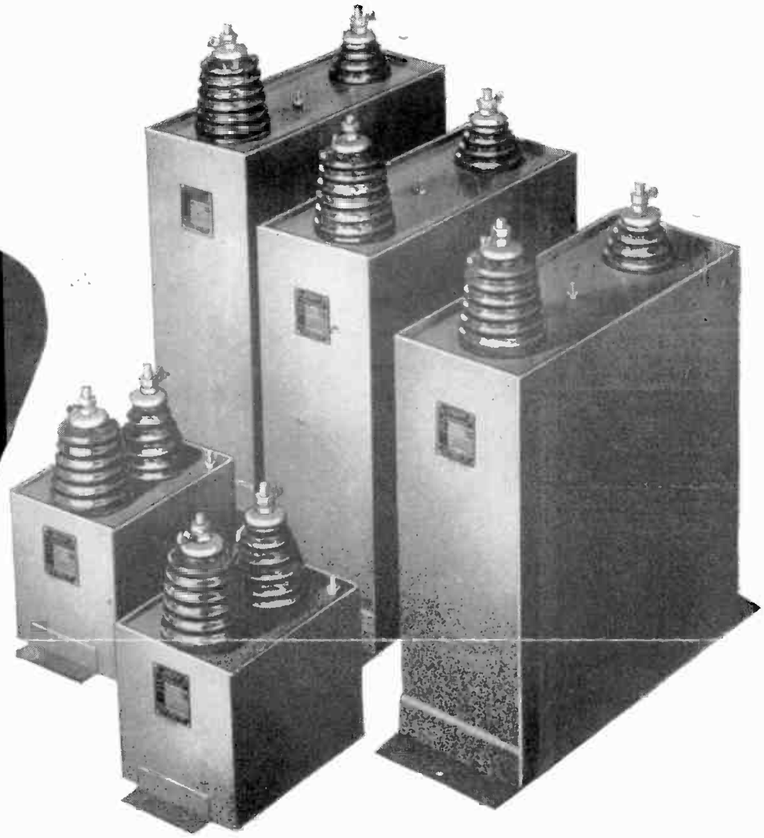
CONSTANT-RESISTANCE NETWORKS
FIG. 3

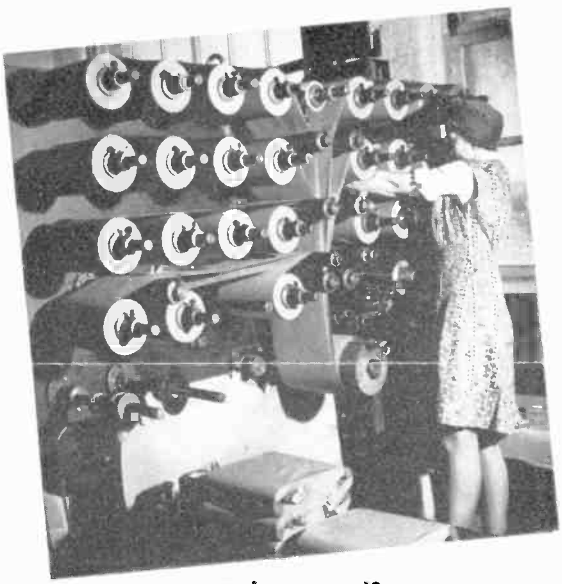
CHART I. Conventional Dividing Networks (See Fig. 2)

f_c=	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	850	900	950	1000
C_1	318.5	212.30	159.24	127.38	106.16	90.98	79.62	70.76	63.70	57.90	53.08	48.98	45.48	42.46	39.80	37.50	35.38	33.52	31.85
C_2	99.47	66.34	49.76	39.81	33.17	28.43	24.88	22.11	19.91	18.09	16.59	15.31	14.21	13.27	12.44	11.72	11.06	10.47	9.95
C_3	159.15	106.15	79.62	63.69	53.08	45.49	39.81	35.38	31.85	28.95	26.54	24.49	22.74	21.23	19.90	18.75	17.69	16.76	15.91
C_4	79.57	53.07	39.81	31.84	26.54	22.74	19.90	17.69	15.92	14.47	13.27	12.24	11.37	10.61	9.95	9.37	8.84	8.38	7.96
C_5	254.64	169.84	127.39	101.90	84.93	72.78	63.69	56.61	50.96	46.32	42.46	39.18	36.38	33.97	31.84	30.00	28.30	26.82	25.46
L_1	25.46	16.98	12.74	10.19	8.49	7.28	6.37	5.66	5.10	4.63	4.25	3.92	3.64	3.40	3.18	3.00	2.83	2.68	2.55
L_2	15.91	10.61	7.96	6.37	5.31	4.55	3.98	3.54	3.18	2.89	2.65	2.45	2.27	2.12	1.99	1.87	1.77	1.68	1.59
L_3	7.96	5.31	3.98	3.18	2.65	2.27	1.99	1.77	1.59	1.45	1.33	1.22	1.14	1.06	0.995	0.937	0.884	0.838	0.796
L_4	31.85	21.23	15.92	12.74	10.62	9.09	7.96	7.08	6.37	5.79	5.31	4.90	4.55	4.25	3.98	3.75	3.54	3.35	3.18
L_5	9.95	6.63	4.98	3.98	3.32	2.84	2.49	2.21	1.99	1.81	1.66	1.53	1.42	1.33	1.24	1.17	1.11	1.05	0.995

C mfds. L mh m 0.6 R_o 10 f cycles

CAPACITOR DREADNAUGHTS





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